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SONAR SIGNAL PROCESSING AND SIMULATION, (U)

1963 H R COURTS, E A TUCKER, A F WITTENBORN

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SONAR SIGNAL PROCESSING AND SIMULATION*

by

H. R. Courts, E. A. Tucker, A. F. Wittenborn
TRACOR, Inc.
Austin, Texas

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SONAR SIGNAL PROCESSING AND SIMULATION

H. R. Courts, E. A. Tucker, A. F. Wittenborn
TRACOR, Inc.
Austin, Texas

The purpose of this paper is to delineate the signal processing gain which can be achieved at sea with the AN/SQS 26 sonar system. This ~~will be~~ is done by describing partial results of a program of work in which signal processing is analyzed by simulating the processing technique to be investigated on a digital computer. Specifically, we ~~will~~ consider the processing gains which can be obtained by using as a transmitted pulse a 0.5 second duration linear FM slide with a bandwidth of 100 cps at a center frequency of 3.4 kc and a system bandwidth of about 130 cps. In order to obtain a basis of comparison, the results for ideal, computer generated FM slides in band limited gaussian noise will be discussed along with the results for FM echoes in reverberation as recorded at sea with the (XN-1) and (XN-2) models of the AN/SQS 26 sonar equipment.

Three processing techniques will be considered, namely:

(1) An ordinary detector consisting of rectification followed by 1/2 second of averaging, to be called the averager below;

(2) A correlator using infinitely clipped signal and reference channels whose output is rectified and averaged for ten milliseconds, called the clipped correlator below;

(3) A correlator using a signal channel sampled in amplitude to 0.1% of full scale and a noise free infinitely clipped reference channel, whose output is rectified and averaged for ten milliseconds, called the linear correlator below.

For the discussion here, input signal-to-noise ratio is defined, in the usual way, as rms signal power over rms noise power in the vicinity of the signal. The output signal-to-noise ratio for the averager is defined as the ratio of peak signal power to the rms power represented by the fluctuations about the mean averager output for noise alone. The output signal-to-noise ratio for each of the correlators, followed by ten milliseconds of averaging is also defined as the ratio of peak signal power to the rms power represented by the fluctuations about the mean of the correlator output for noise alone.

Consider first the case for band limited gaussian noise and ideal computer generated echoes. Figure 1 shows the average output signal-to-noise ratio as a function of the input signal-to-noise ratio for the three processors to be discussed here.

As expected, the largest processing gain is obtained with the linear correlator. Also as expected, the processing gain is independent of the input signal-to-noise ratio. The averager shows significant processing gain for large input signal-to-noise ratios, but for small input signal-to-noise ratios it falls off as the square of the input signal-to-noise ratio, as is well known. The clipped correlator does not have much gain for large signals (indeed, the gain may be negative) but for small input signals the gain approaches an assymptote only about 1.0 to 2.0 DB below the linear correlator. The loss of gain for large signals is often academic. At 0 DB input signal-to-noise ratio the clipped correlator is approximately 3 DB below the linear correlator.

The curves shown in Figure 1 were obtained by averaging many independent measurements. Figure 2 shows the individual measurements for the averager. Here all of the points fall on a line since the same basic measurement is used to determine both the input signal-to-noise ratio and the output signal-to-noise ratio.

Figure 3 shows the individual measurements for the clipped correlator. Here the scatter gets very broad as the input signal-to-noise ratio decreases. Figure 4 shows the scatter for the linear correlator.

In the course of taking these measurements the question as to how many points are needed to get a good measurement of average output signal-to-noise ratio naturally comes up. If we assume that the distribution of the measured values about the expected theoretical value is described by gaussian statistics, then the number of measurements required to have 95% confidence that the mean measured value is within ± 1 DB of the true value is,

$$N = \left(\frac{s}{.116m} \right)^2$$

where

m = The expected mean signal-to-noise ratio

s = The standard deviation about this value

Although we know that the distribution of the measured values about the theoretical mean is not precisely gaussian, we assume that it is for lack of a better description. Under this condition, figure 5 shows the number of measurements needed for 95% confidence that the mean of the measurement is within 1 DB of the theoretically expected mean for the three processors and

also the input signal-to-noise ratio. Note that even for an output signal-to-noise ratio as high as + 17 DB approximately 10 measurements should be made. By a process of trial and error, each point used to determine the curves shown earlier was based on a sufficient number of measurements.

Next we want to consider the performance of these three processors using data recorded at sea in the bottom bounce mode for 20° and 30° depression angle, where the background is presumably reverberation. The first processor to be considered is the averager. Figure 6 shows the output signal-to-noise ratio vs. input signal-to-noise ratio for a guassian noise background and a reverberation background. The difference between the two curves is of interest. The ratio of the standard deviation to the mean in the absence of signal is shown for both gaussian and reverberation background. From this we expect about a 9 DB decrease in the gain for the reverberation case simply from the definition of output signal-to-noise ratio. It should be noted that the ratio quoted is only a typical ratio and in general is dependent on the mode of operation, depth, sea state and other parameters. Figure 7 shows a composite curve obtained using sea data. Here note that the ratios of standard deviation to the mean are essentially independent of whether the background is gauss noise or reverberation for the two correlators.

Although most of these results are perhaps not new to some people, there has been doubt in other people's minds as to whether or not predicted processing gains, or any processing gain at all, could be achieved with the clipped or linear correlator in the AN/SQS 26. Specifically, the question is often raised as to whether or not the bottom bounce and echo formation processes destroy the coherence of the pulses to such an extent that no significant improvement over the averager can be obtained. We believe that the results of figure 7 speak for themselves. Note that at about -4 to -6 db input signal-to-noise ratio, the clipped correlator results in a processing gain some 8 to 12 db better than the averager. These results were obtained by averaging over approximately 600 echo ranging cycles.

Figure 8 is the probability of exceeding a threshold for a gaussian statistic and for the statistics describing the correlator output in the absence of signal. We have found that the statistics of the clipped and linear correlator are essentially identical and also that they are the same for reverberation or gaussian noise input. The statistics at the output of a correlator may be approximated by a Chi-square distribution with approximately eleven degrees of freedom. Note that at the 3s point the false alarm rate for the correlator output is nearly an order of magnitude larger than the gaussian curve with the same mean.

The final curve, figure 9, shows the signal-to-noise ratio at the output of a clipped correlator as measured on sequential echo ranging cycles. Three sequences are shown. The rms fluctuation in echo strength from ping to ping is of order 8 to 10 db.

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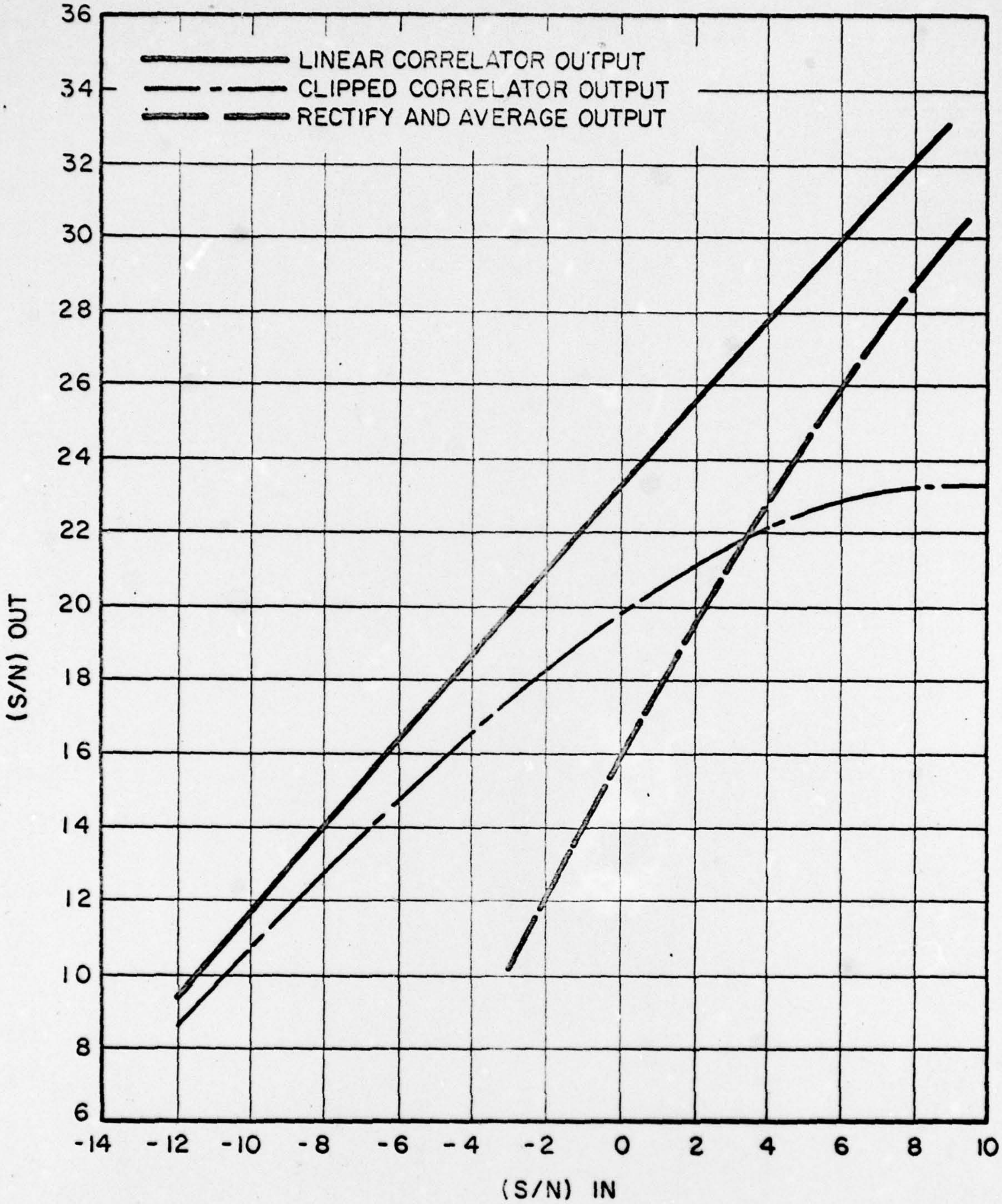

Fig. 1-COMPOSITE CURVE

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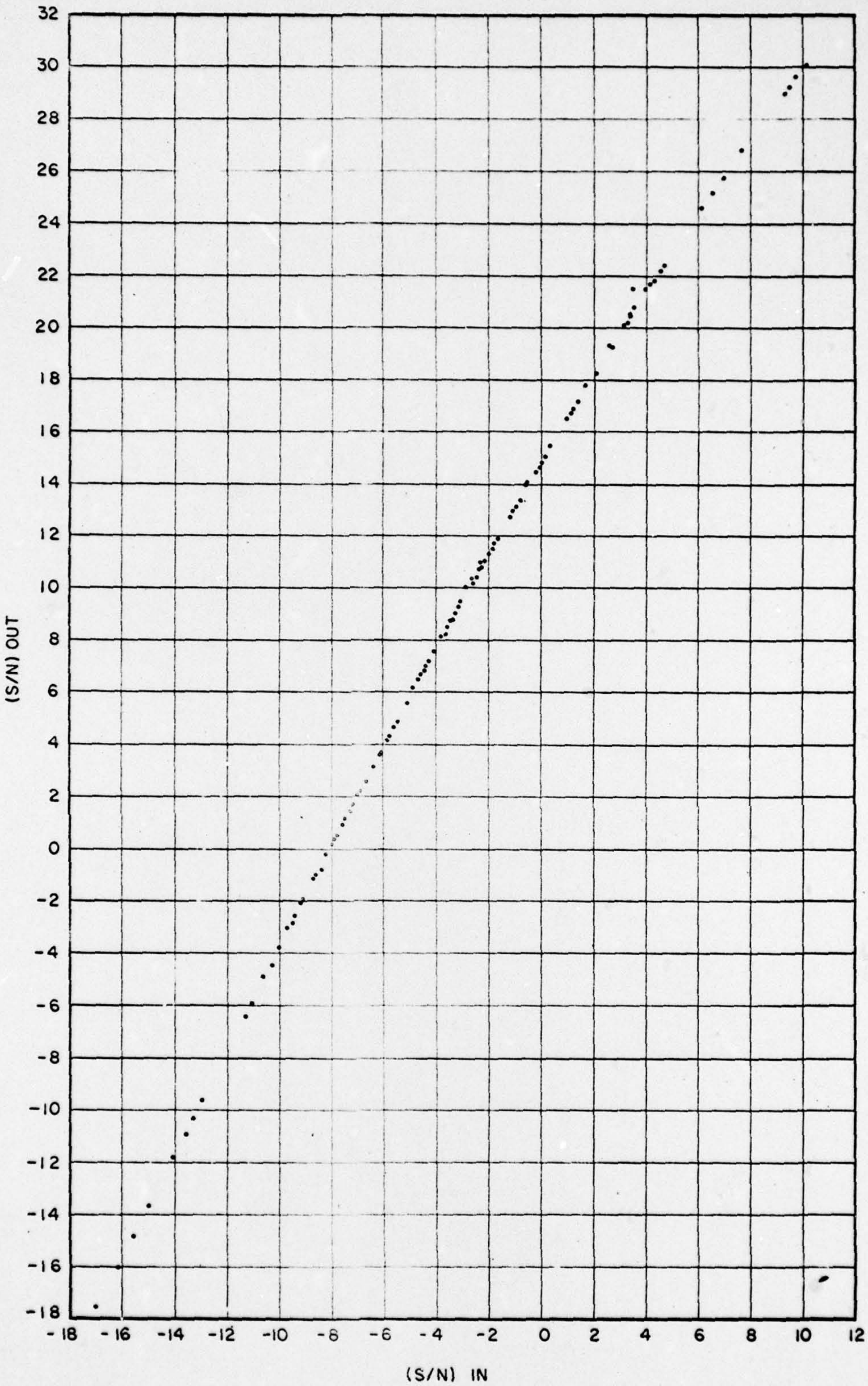

Fig. 2 – HALF SECOND AVERAGE OUTPUT, IDEAL SIGNALS GAUSSIAN NOISE

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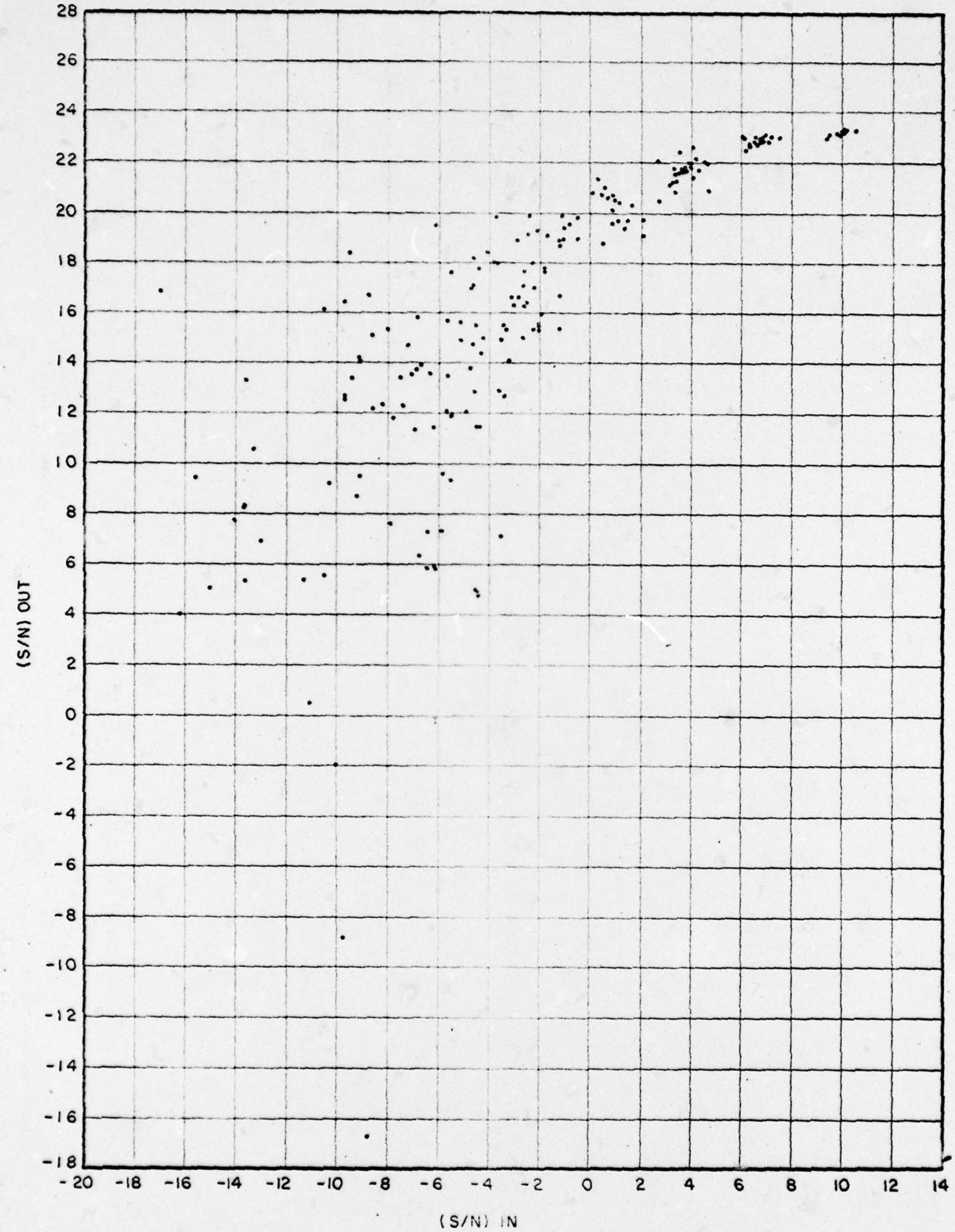

Fig. 3 - CLIPPED CORRELATOR OUTPUT, IDEAL SIGNALS, GAUSSIAN NOISE

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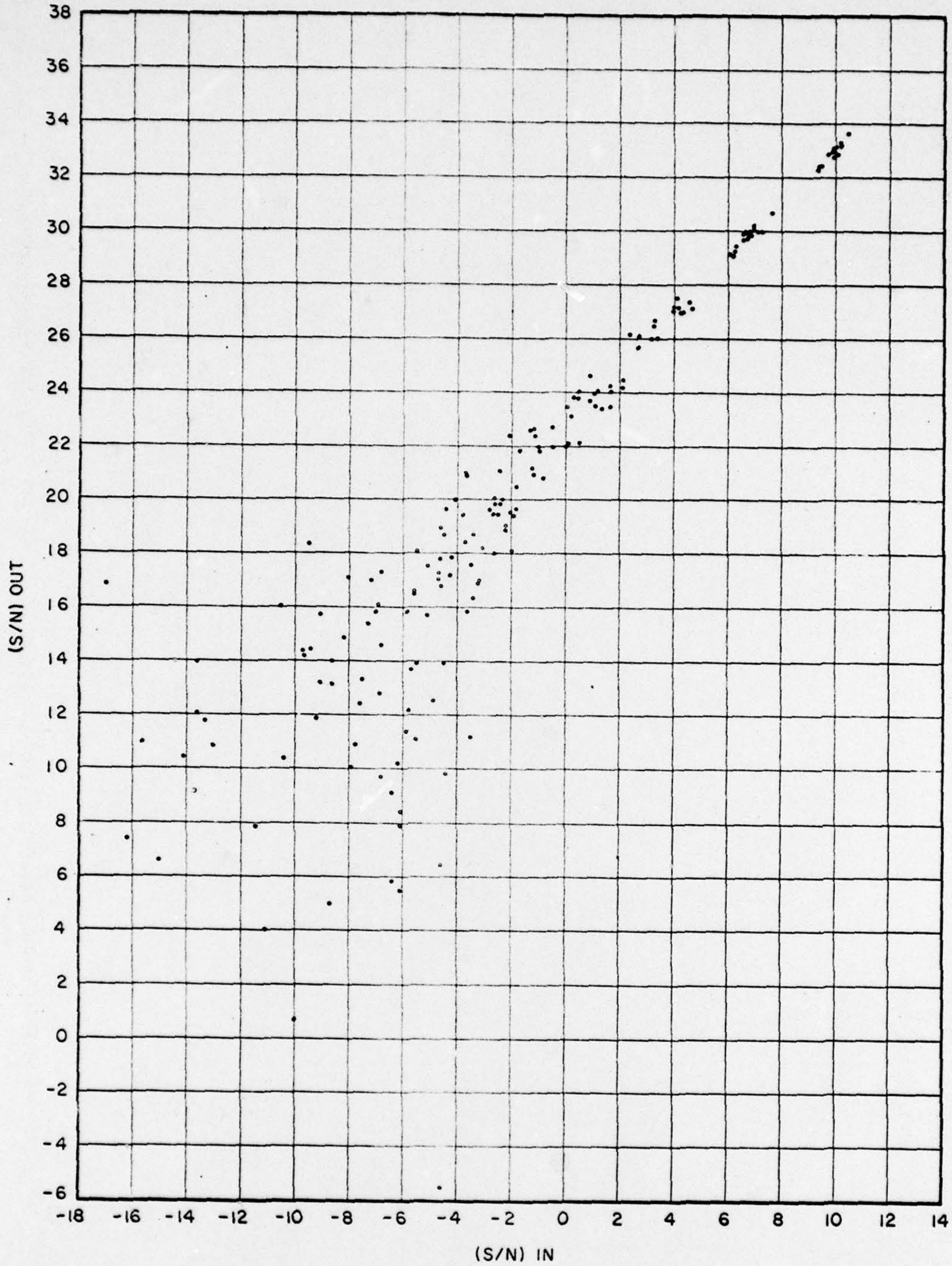

Fig. 4 – LINEAR CORRELATOR OUTPUT, IDEAL SIGNALS, GAUSSIAN NOISE

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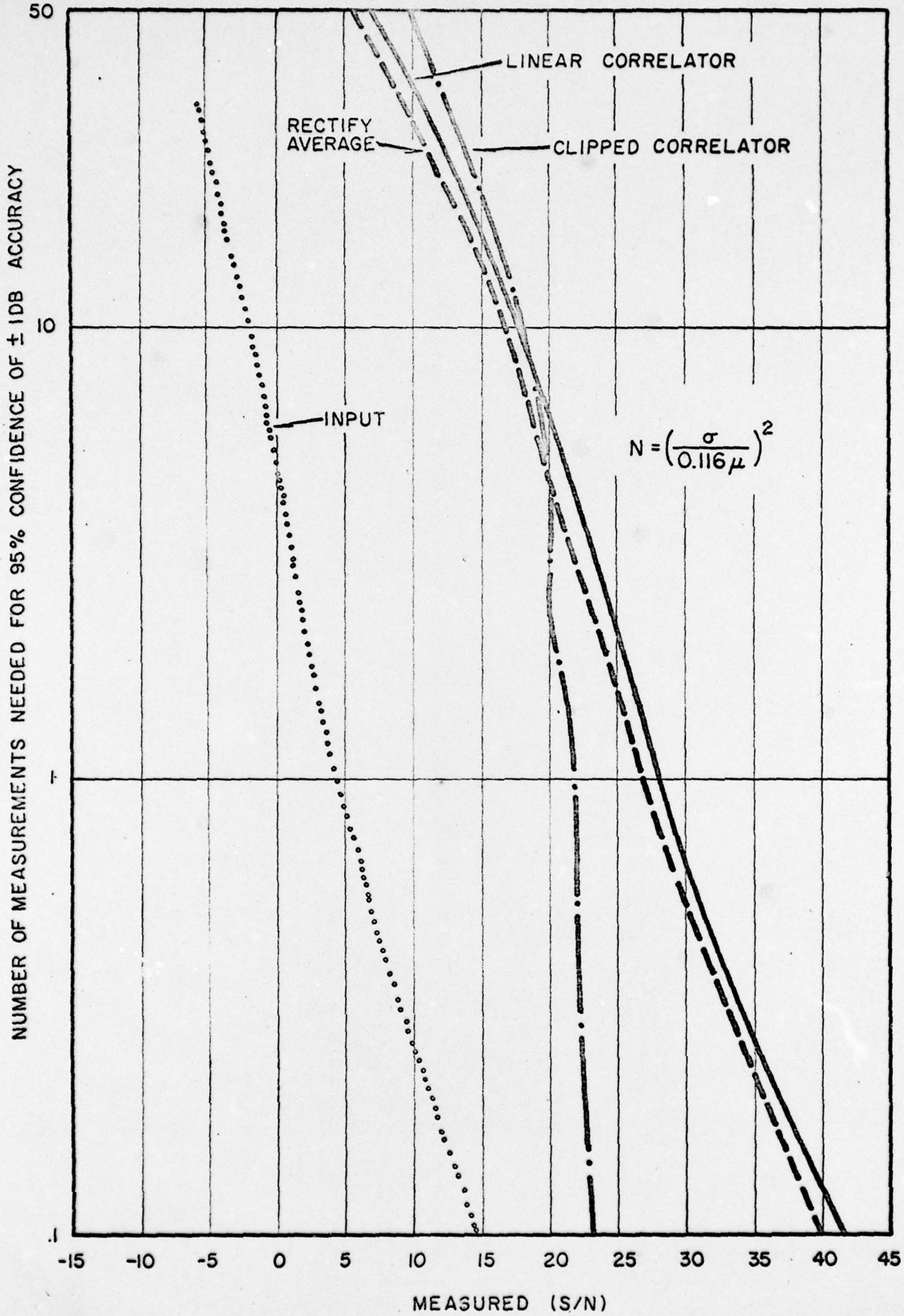

Fig. 5

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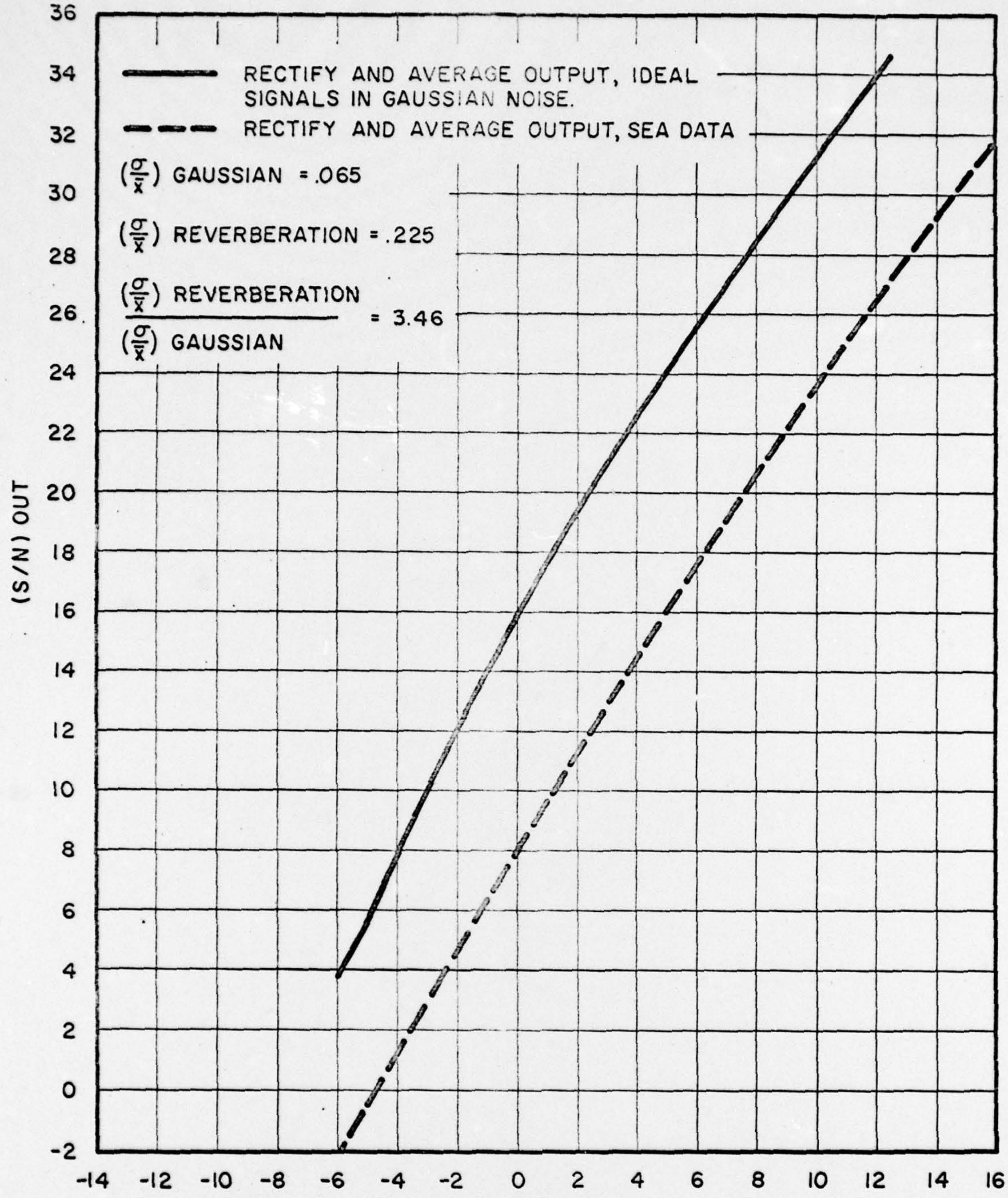

Fig. 6 - RECTIFY AND AVERAGE

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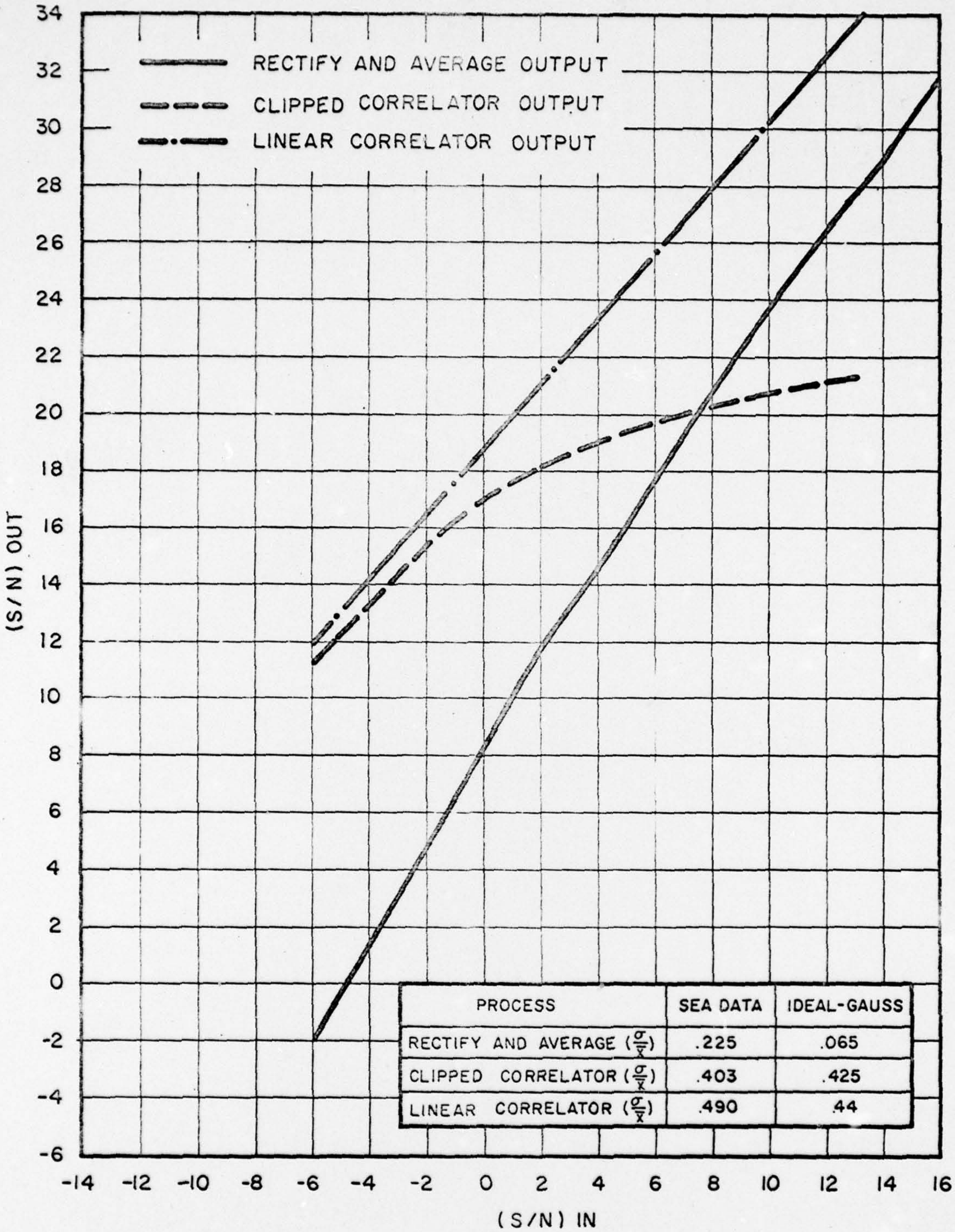

PROCESS	SEA DATA	IDEAL-GAUSS
RECTIFY AND AVERAGE $(\frac{\sigma}{\bar{x}})$	.225	.065
CLIPPED CORRELATOR $(\frac{\sigma}{\bar{x}})$	.403	.425
LINEAR CORRELATOR $(\frac{\sigma}{\bar{x}})$	.490	.44

Fig. 7 - COMPOSITE CURVE, SEA DATA

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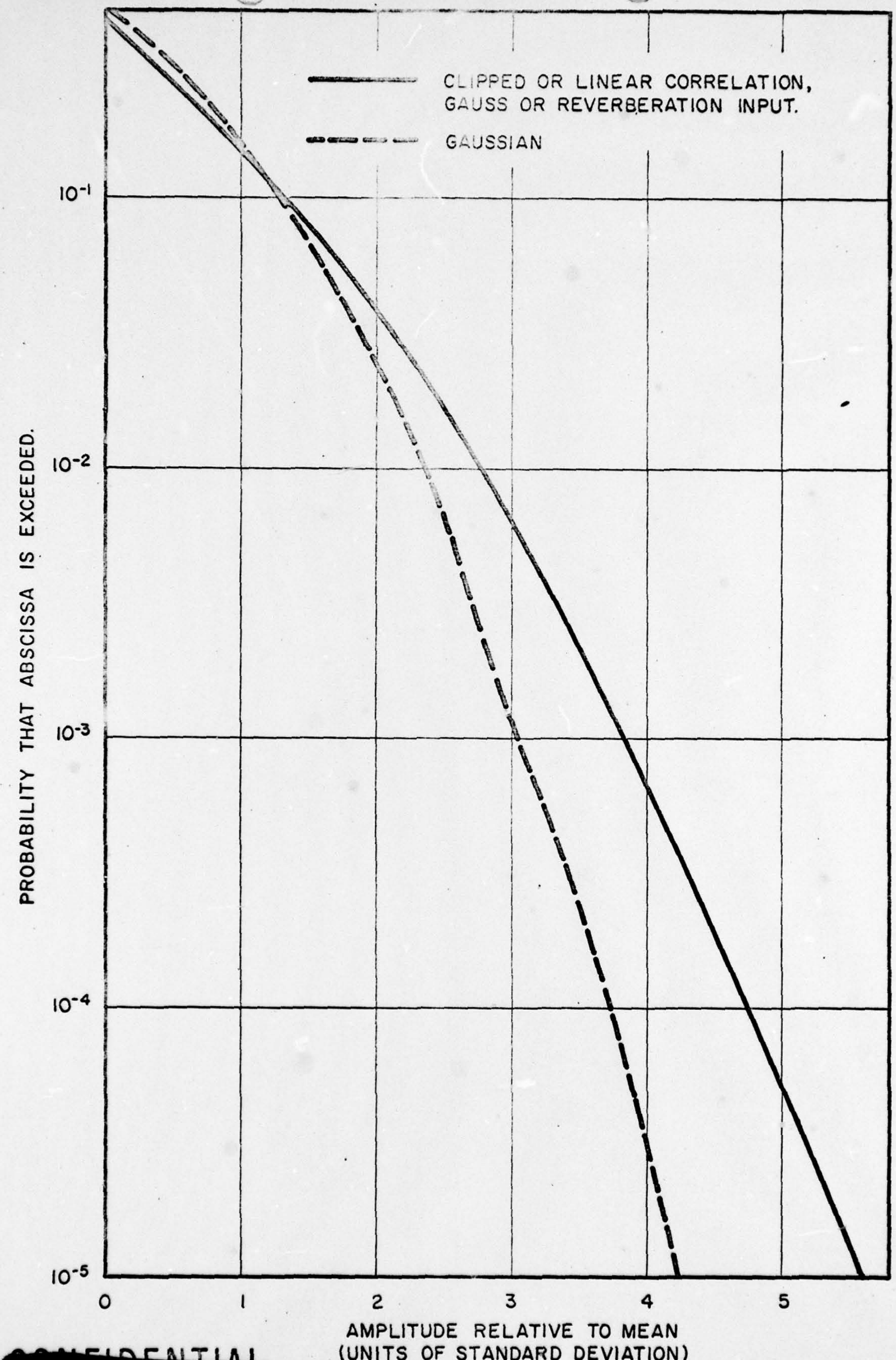

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Fig. 8

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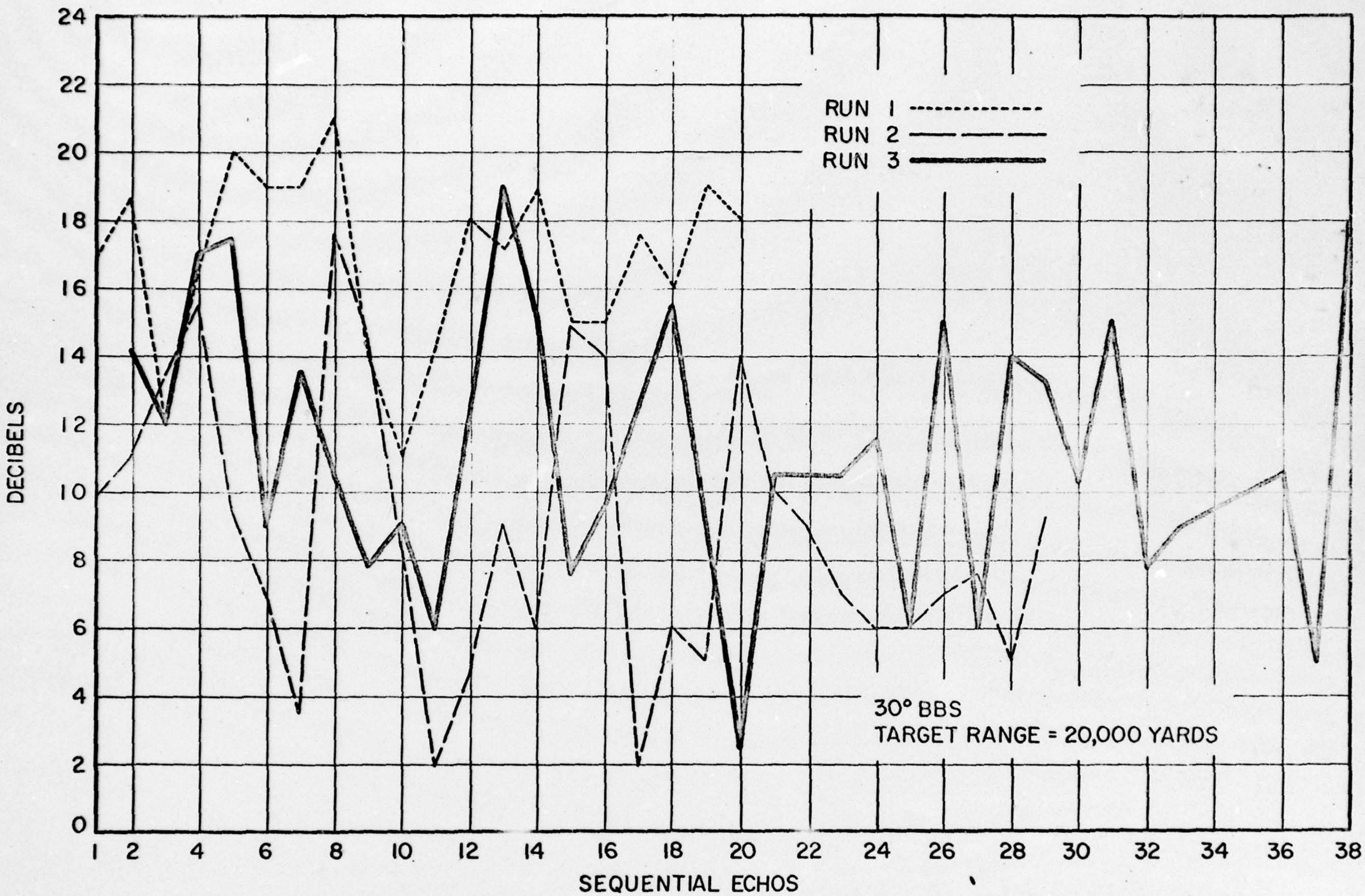

Fig. 9 - SEQUENTIAL ECHOS, 3 SEPARATE RUNS, CLIPPED CORRELATOR OUTPUTS

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